CHRONOPHOTOGRAPHY, OR PHOTOGRAPHY AS APPLIED TO MOVING OBJECTS.[1]

THIS subject forms the basis of a very interesting article, in the *Revue Générale des Sciences*, by Prof. Marey, who explains a new method for the analysis of the movements of various bodies that are under consideration, more especially in biological than in physical science. Our readers may remember a book that appeared in the year 1882, entitled "The Horse in Motion," published under the auspices of Leland Stanford. Mr. Stanford, wishing to study the relative positions of the feet of horses in rapid motion, employed Mr. Muybridge, who was then noted as a very skilful photographer, to carry out a series of experiments. The success which rewarded their endeavours revealed so much that seemed of importance, that he determined to make a complete study of the subject, and with this intention employed Dr. J. D. B. Stillman, to whom he intrusted the undertaking.

The method the last mentioned adopted was very similar to that employed later by Mr. Muybridge, the differences being that he only made use of one series of cameras, and that the plates were exposed by the breaking of threads by the moving object. The revolving disk was also in vogue then, for taking movements of running dogs, flights of birds, &c., only it was not used to obtain the movements of the horse, as it was found extremely difficult to set the apparatus in motion at the exact moment required, and to regulate it to the speed of the horse.

It is important, next, to refer to the results obtained by Mr. Muybridge in his later experiments, carried out at the University of Pennsylvania, which were published in a large book containing all the series of photographs. The following is a brief account of the method he used.

It consisted in the employment of three batteries, each containing twelve cameras. The object of working with *three* batteries was to enable him to obtain photographs from three points of view simultaneously, and the manner in which he arranged them was as follows. One battery was set parallel to the track along which the object to be photographed moved, so that its image would be formed on each plate successively as it passed before the lenses; and since the distance between the object and each camera was constant, only one focus was required. Placed at right angles to this track, and directed up and down it, were fixed respectively the two other batteries, and the cameras in these were so adjusted as to have in their field of view the same series of positions as seen in the first battery, only of course from two different standpoints; but since in this case the distance between the object and the cameras was always varying, each of the latter had to be specially adjusted for its own focus.

The instantaneous shutters of all the cameras were connected by wires to a set of twelve metal studs situated on the circumference of a disk, each stud being fastened to a set of three wires, each of which comes from the first camera in each battery, the second set from the second cameras, and so on.

A second disk, placed close by, and carrying a brush, was made to rotate, the brush coming in contact with each of the studs in turn. By this means, a series of currents was sent to these groups of three cameras intermittently; and, as each contact was made, three shutters were simultaneously released—one in each of the series—giving a group of three synchronous pictures of the object that was moving on the track, showing the fore, hind, and lateral views.

One of the first attempts of Prof. Marey consisted in placing on each foot of the moving animal elastic cushions, which were connected with a chronograph by means of flexible tubes. As each foot came in contact with the ground, a record of the impact was obtained, from which interesting results were deduced relating to the peculiarities of the succession of steps, and the time-intervals separating them.

Having referred above to the earlier experiments, we will now mention the very recent work carried out by him. The method that he here adopts differs considerably from his first endeavour, and also from that employed by Muybridge and Stillman. Instead of using many cameras, and therefore many plates, he works with one camera and one plate, and it is on this plate that he produces his *series* of photographs. The objects that he wishes to study move in front of a dark background, which is situated directly opposite the camera. Fitted to the camera is a large disk with openings in it, and which is capable of quick or slow rotation in a vertical plane.

During the passage of *one* of these openings before the lens, the moving object has its image cast on the photographic plate, and is there recorded: as soon as the aperture has passed, no light can fall on the plate until the next opening comes opposite. As soon as this arrives, another picture is taken in the same way, but, during the interval that has just elapsed, the object, having changed its place, forms its image naturally on another part of the plate. By continuing this process, one can easily see that, on the plate being developed, a series of successive images will be seen extending from one side to the other.

With a very slow-moving object, this method cannot be applied so well, unless an intermittent rotation be given to the disk, as we should have a series of overlapping images quite undistinguishable from one another. The following illustration (Fig. 1) is an example of a picture obtained by using a continuously revolving disk. Between each exposure it will be seen that the horse has not even travelled its own length, but only a little over half, so that the mingling of all the images results in a picture that is useless for purposes of study. The question which was raised from such results as shown in the above figure may be formulated thus: How is it possible to reduce the surface of the object, and yet be able to record the movements of its principal members photographically? The following very artful device, which is shown in the next illustration (Fig. 2), exemplifies the manner in which Prof. Meyer solved the question. By dressing the object in black, employing a dark background, and placing on the members, the movements of which he wished to investigate, white lines and spots, he was able to increase the number of exposures per second without introducing overlapping, and to record the successive positions taken up by them.

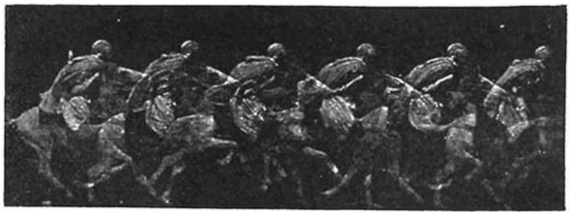

FIG. 1.—Arab horse at full gallop.

We must mention here that the experiments were only carried out with a man as object; if a horse had been taken, it would have been necessary to have dressed it in black, and to have put the distinguishing marks on *either* one of the fore *or* hind legs, and not on both at once; otherwise there would have been two complete series of images recorded on one plate at the same time, and overlapping each other.

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[1] We are obliged to the editor of the *Revue Générale des Sciences* for permission to use the illustrations reproduced in this article.

In another illustration we have an interesting set of attitudes assumed by a running man dressed in this costume (Fig. 3). The lines in the figure indicate the sequence of positions in which the above-mentioned distinguishing marks are found at each exposure; and the resulting diagram also shows that the number of images capable of being photographed in a given time is very largely increased, while the overlapping is only slightly apparent.

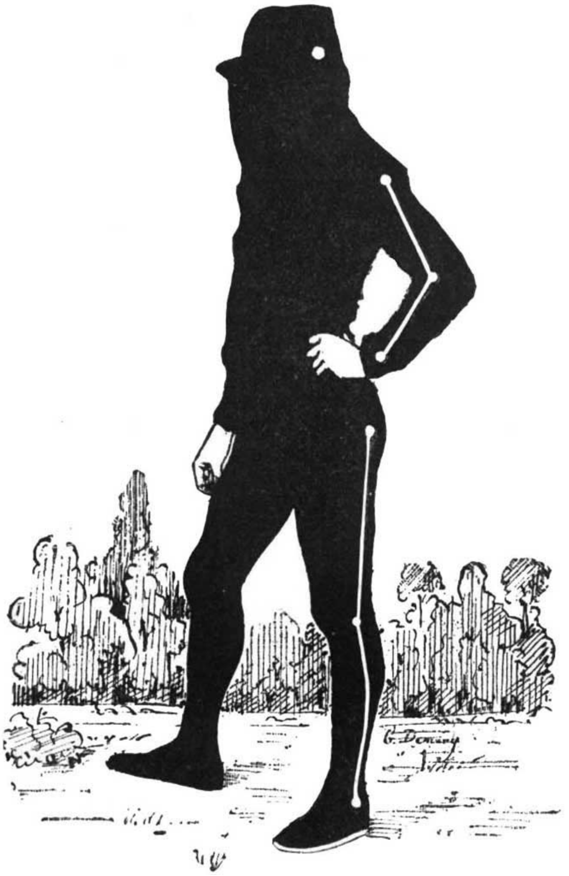

FIG. 2.—Man dressed in black, and consequently invisible when passing before a dark background. The white lines which are shown on his arms, legs, and on the sole of one foot are the only parts the successive phases of which can be recorded.

Another case is that shown in Fig. 4, which represents a man jumping. The several phases of movement are here also well discernible, and the images were recorded at the rate of twenty-five per second.

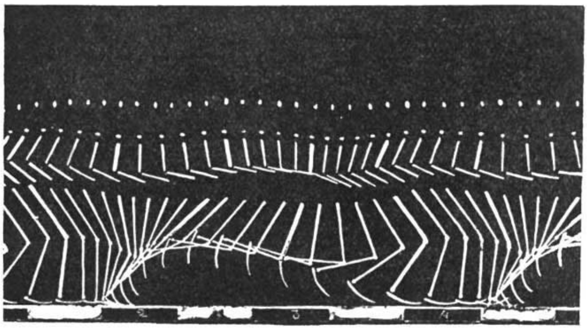

FIG. 3.—Images of a runner, showing the white marks which represent the attitudes of the principal members. Chronophotography on a fixed plate.

Although the method employed above suited admirably for such purposes as we have mentioned, yet Prof. Marey found that he could not use it without modification for all the cases to which he wished to apply it. The apparatus which he then constructed, and of which a complete detailed account is given in his article, is shown in Fig. 5, and differs in many particulars from the former one, the chief characteristic about it being that films are employed which are capable of rapid lateral movement. By means of this moving film it is possible to obtain, in a very short space of time, a large number of separate pictures, for, during each exposure, a new part of the film is brought opposite the lens of the camera, held there, and then slipped along. The apparatus itself is of a most ingenious construction, and the three most important parts consist of a driver, a clamper, and an elastic arm.

In the figure, L represents the driver, and it is due to its action that the motion of the paper is produced; it consists of a wooden cylinder, the surface of which is covered with india-rubber, and round which the band of paper passes when made to travel from one bobbin to the other.

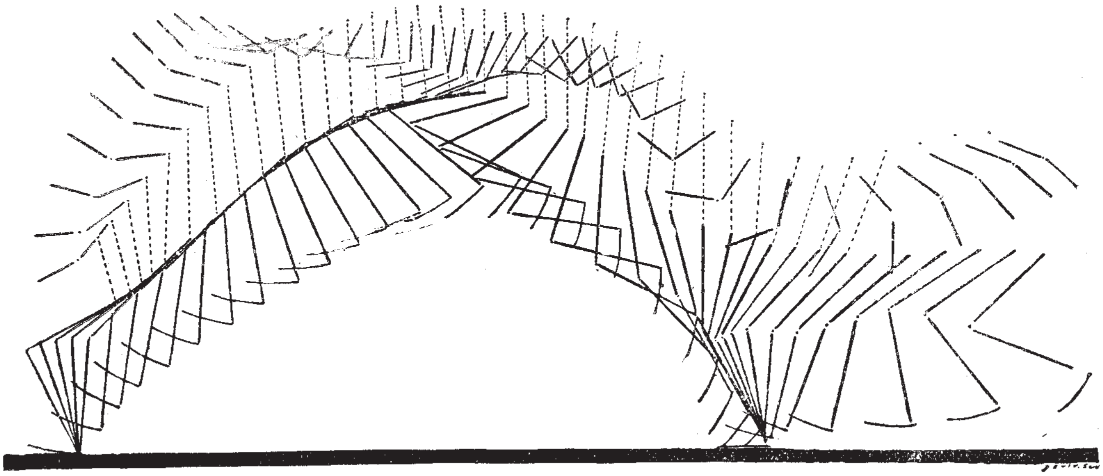

FIG. 4.—Analysis of the phases of a running high jump. Taken on a fixed plate (twenty-five images per second).

In the case of the clamper, marked C′ in the drawing, its action is to press the paper against the side of the chamber during each exposure, and this is carried out by means of a series of cams placed on a small circular horizontal disk (marked C). It might be supposed that, with very short exposures obtained by means of a very rapid shutter, the clamper would be found quite unnecessary, as the horizontal distance traversed by the band of paper during an exposure would be practically *nil*, or at any rate small enough to produce no visible effect on the picture produced; but this is not the case, for Prof. Marey says that by experience the only good images obtainable were made with the use of the stop.

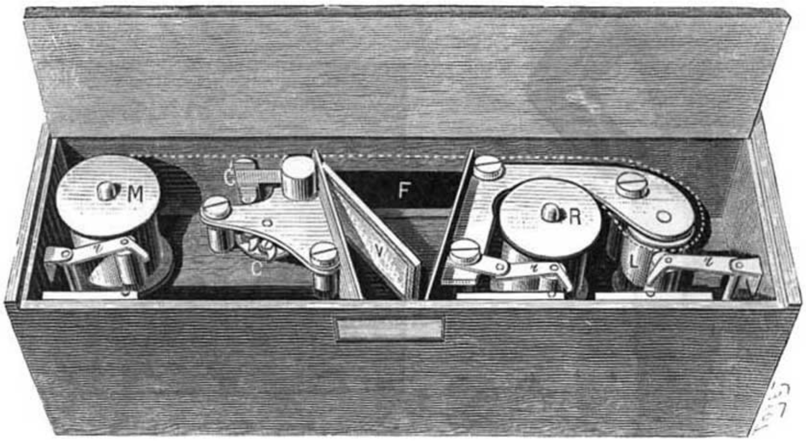

FIG. 5.—The chamber in which the images are formed, with the lid raised. M and R are the drums on which the films are rolled off and on respectively; *r*, *r*, *r*, small rollers pressing the film on the cylinders; L, the driver, with its pressing cylinder; F, the aperture for the admission of the image; V, ground glass with hinged motion. The dotted line indicates the path of the band of film; C′ and C, the clamper and its cam, which produces the intermittent action of this band.

Owing to the quickness of the action of the driver, and the instantaneous blow given by the clamper to the paper at each exposure, an elastic arm is made to come into play to relieve the paper of any strain or force to which it may be subjected.

Many readers may remember the very interesting article in a former number of NATURE (vol. xl. p. 78), written by Prof. Ray Lankester, relating to the Muybridge photographs. Towards the end he says: "For my own part I should greatly like to apply Mr. Muybridge's cameras, or a similar set of batteries, to the investigation of a phenomenon more puzzling even than that of 'the galloping horse.' I allude to the problem of 'the running centipede.'" He then goes on to say: "I am anxious to compare with these movements the rapid rhythmical actions of the parapodia of such Chætopods as Phyllodoce, . . . passing on to scorpions and spiders, and then to shrimps, lobsters, . . ."

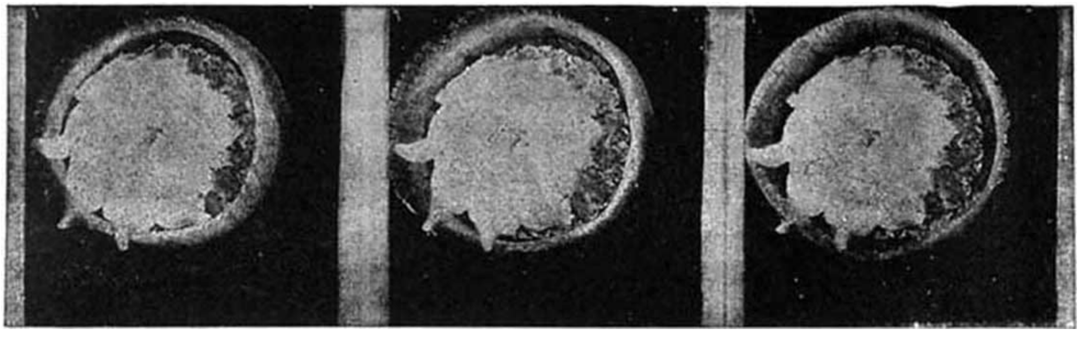

FIG. 6.—Medusa swimming horizontally, whilst moving away from the apparatus (negative).

Although, at the first glance, one cannot quite see how Muybridge's principle, or, at any rate, a slight change of it, could be applied to interpret the gait of the centipede, yet in Prof. Marey's instrument Prof. Lankester will, we hope, find just the kind of apparatus to carry out the various suggestions to which he referred. In fact, the instrument has already been employed in producing pictures representing aquatic locomotion and the following illustration (Fig. 6) shows a Medusa swimming, while Fig. 7 shows the phases of movement that a star-fish undergoes in order to turn itself over.

The interesting point is displayed in the last four pictures of the series. Counting from the bottom, No. 5 shows the position just before one of his "rays" leaves the ground and just when he begins to grip it with the other two; having this grip, he is able to dispense with the use of the other ray, and so raises the other three as shown in No. 6. No. 7 illustrates the position of unstable equilibrium as obtained by means of the preceding movements, while the last one exemplifies stable equilibrium again.

The time occupied in the above evolutions is not so short as may be supposed, but lasts sometimes from ten to twenty minutes, the intervals in time between two of the above pictures being about two minutes.

The movements of the eel have also been studied in this way, and the series of movements represented in

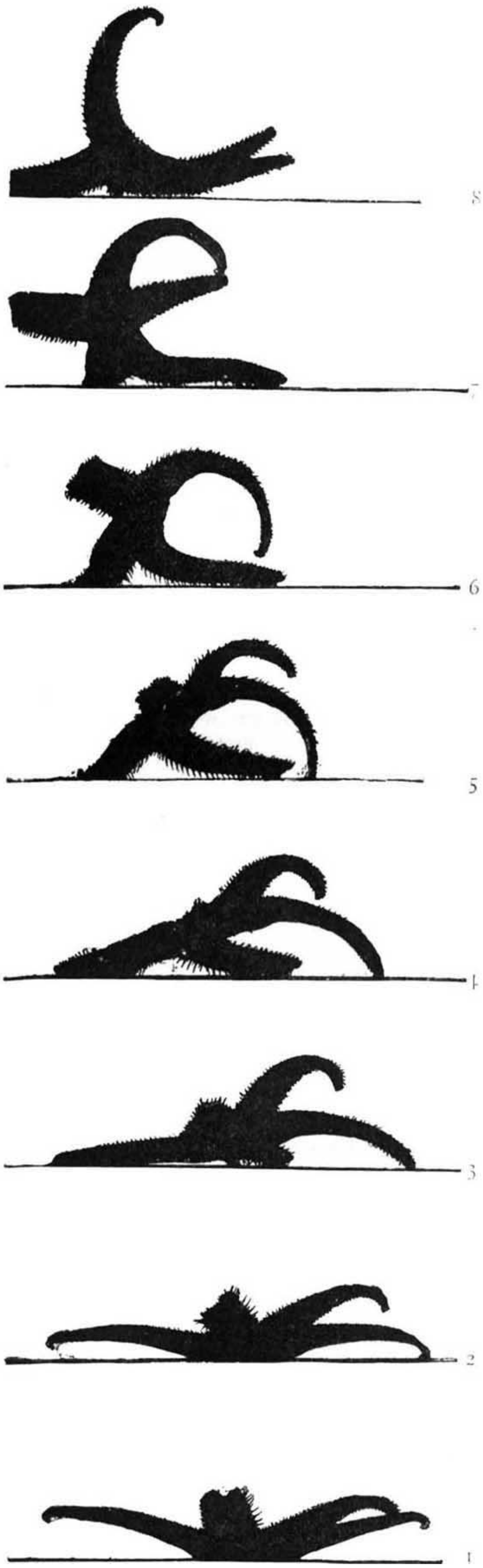

FIG. 7.—Series of phases performed by a star-fish in turning itself over.

Fig. 8, illustrating an eel swimming horizontally, brings out clearly the wave produced by the effect of the undulatory movement of the body, propagating from the head to the tail.

In observing the movements of many other different species of serpents, both in and out of water, Prof. Marey says: "La reptation des uns et la natation des autres présentent de grandes analogies avec la natation de l'anguille, mais nous n'y avons pas trouvé la même régularité des mouvements."

But in the study of the movements of objects as small as these, Prof. Marey does not here conclude his observations, but has constructed a special piece of apparatus, as shown in Fig. 9, for recording the movements of microscopical objects. The general working of this apparatus can be seen at a glance. C is the large condenser which concentrates all the light from some artificial source on to the small holder p, in which the object is placed. The micrometer objective marked O, is placed on the other side of this holder, but in the axis of the condenser. The micrometer head B regulates the distance of p from O, and can be moved either by the rod *mv*, or by its milled head. An important adjunct to the instrument is the microscope that is placed obliquely at the side of the camera; by its means, and by that of a small prism that can be placed in the axis of the light by simply pulling or pushing the knob P, the object about

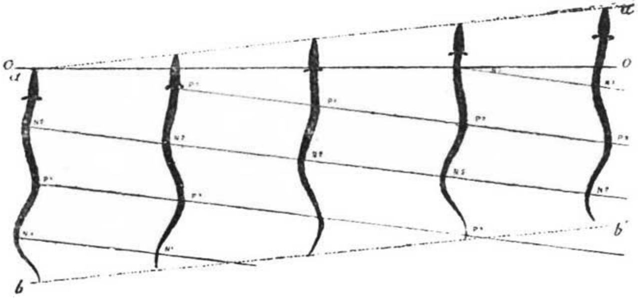

FIG. 8.—Eel swimming in a horizontal plane. The horizontal line *oo* shows plainly the inclination of those lines which join the crests and troughs of the waves formed by the body, so that the velocity of progression of the animal is expressed by the inclination of the line *oa*.

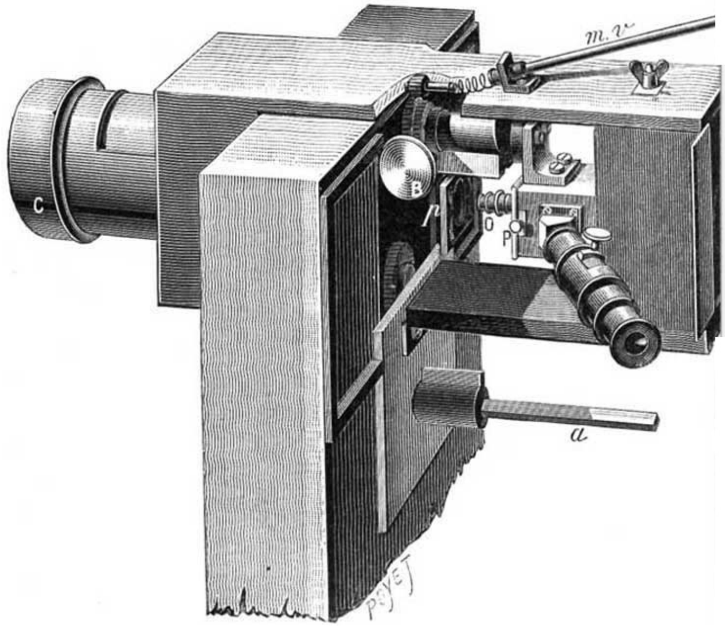

FIG. 9.—Special piece of apparatus for studying the movements of microscopical objects.

to be photographed can be observed just before exposure, which insures the centrality of its image on the sensitive film.

The extension of this branch of chronophotography, if taken up and developed, may be of great use to medical science, for many occurrences happen where such an apparatus as the above would be invaluable. One of the examples done by this method is shown in Fig. 10, and illustrates the movements of Vorticellæ, which retract their stalks in spiral fashion. Many other proposals, not yet carried out, are mentioned by Prof. Marey, and include the production of photographs showing the movements of blood corpuscles in the capillary tubes, the intimate actions of the contraction of the fibre of the muscles, and the waves which pervade them

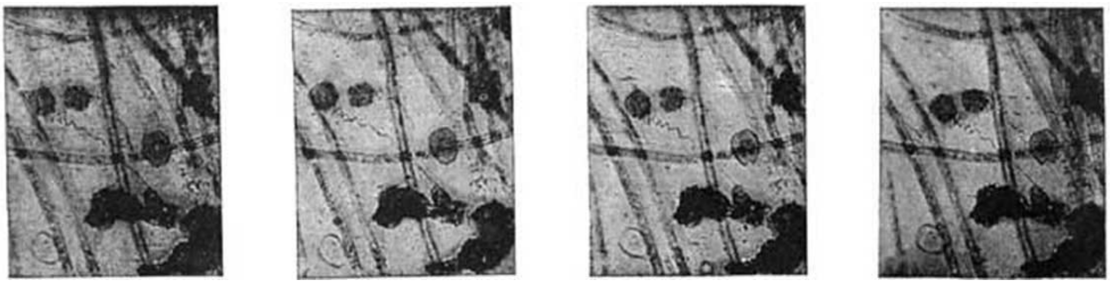

FIG. 10.—Showing the movements of Vorticellæ. The phases of movements must be read from left to right.

Prof. Marey also applies chronophotography to movements of objects in physical as well as in biological science, but although several cases are mentioned, we will only refer here to the instance he gives of the falling ball (Fig. 11).

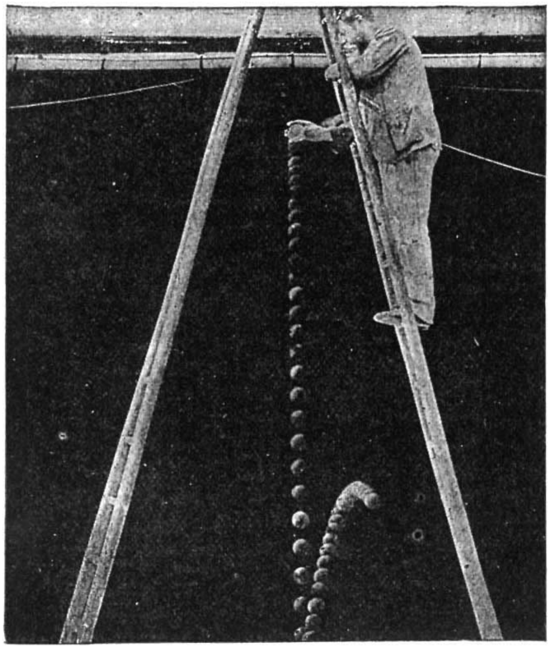

FIG. 11.—Series of positions taken up by a falling ball studied by chronophotography on a fixed plate.

The intervals between each image of the ball, although different in space, are equal in time, and the illustration brings out clearly the gradual increase of the velocity; while on its upward bound the decrease is also apparent, perhaps not so much, on account of the ball approaching the camera.

Although we have not quite touched on all the subjects referred to in the very interesting article by Prof. Marey, yet we trust we have given the reader an idea of what kind of work has been going on in this direction, and the methods that have been adopted to produce such good results. The branch that we look forward to being greatly extended is that in which the microscope takes the prominent part.

W.

SIR GEORGE BIDDELL AIRY.

WE greatly regret to have to record the death of Sir George Biddell Airy, whose name has been familiar to the scientific students of more than one generation. He died on Saturday evening last, in his ninety-first year. In the summer he received by a fall an injury which rendered a surgical operation necessary. Although at the time this seemed to be successful, he never really recovered from the shock to his system.

On October 31, 1878 (vol. xviii. p. 689), we published a portrait of Sir George Airy in our series of "Scientific Worthies," and at the same time we gave a full account of his work as a man of science. We need not now, therefore, do more than note the main facts of his career.

He was born at Alnwick, Northumberland, on July 27, 1801, and received his early education at private schools in Hereford and Colchester, and at the Manchester Grammar School. In 1819 he entered Trinity College, Cambridge, as sizar. Here he soon gave proof of a remarkable aptitude for mathematics, and in 1823 he graduated as Senior Wrangler. In the following year he was elected a Fellow of his College, and in 1826 he became Lucasian Professor of Mathematics. He was full of enthusiasm for experimental science and applied mathematics, and in 1824–25 had published papers on "The Lunar and Planetary Theories," on "The Figure of the Earth," on "The Undulatory Theory of Optics," on "The Forms of the Teeth of Wheels," and on "Escapements." After his appointment to the Lucasian Professorship, he continued to make important contributions to the knowledge of such subjects, devoting himself with especial ardour to the study of undulatory optics, which was at that time a new field of research.

He was elected Plumian Professor of Astronomy in 1828, a position with which was associated the directorship of the Astronomical Observatory. Here he superintended the erection of several instruments, and—in accordance with the example set by Maskelyne, and followed by Bessel and Struve—introduced a thoroughly efficient system for reducing the observations, which were printed annually. He also carried on theoretical studies. In 1831 he published in the Transactions